LASER SURFACE MODIFICATION OF CR-MO POWDERS ON GREY CAST IRON FOR SURFACE PROPERTIES IMPROVEMENT

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Doctor of Philosophy (Mechanical Engineering)

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SUPERVISOR'S DECLARATION

We hereby declare that We have checked this thesis and in our opinion, this thesis is adequate in terms of scope and quality for the award of the degree of Doctor of Philosophy (Mechanical Engineering).

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STUDENT'S DECLARATION

I hereby declare that the work in this thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Malaysia Pahang or any other institutions.

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ABSTRAK

Kebelakangan ini dalam industri, komponen yang dihasilkan daripada besi tuang kelabu (seperti lapisan silinder dan disk brek) mengalami kecatatan kehausan dan kekaratan disebabkan oleh suhu yang tinggi, tekanan dan geseran yang menyumbangkan kepada pelbagai keadaan yang tegang. Tujuan kajian ini ialah untuk mengenalpasti dan membuat perubahan pada permukaan besi tuang kelabu dengan menggunakan kaedah mod proses laser nadi. Untuk mengukuhkan permukaan tersebut penambahan sebatian Cr-Mo diletakkan di atas permukaan. Hubungan parameter untuk proses ini dianalisi dengan menggunakan analisis statistik. Saringan awal rekabentuk eksperimen telah membawa kepada lebih banyak penemuan untuk mengoptimumkan rekabentuk dengan lebih terperinci. Dalam kajian ini, Laser Nd:YAG sistem model 300HPS dengan panjang gelombang 10.64 μm telah digunakan. Kajian awalan telah dilakukan dengan menggunakan rekabentuk model eksperimen 2 peringkat faktor pada laser cairan permukaan dengan saiz laser 1.0 mm, 1.2 mm, 1.4 mm dan 1.7 mm. Kajian awalan ini adalah untuk mengenalpasti parameter laser yang optimum dan saiz laser yang sesuai untuk menghasilkan bentuk geometri, kekasaran dan kekerasan yang baik pada besi tuang kelabu. Berdasarkan pada pengoptimuman laser parameter dalam laser cairan, saiz laser 1.0 mm dengan P_P, PRF dan S diantara 800 hingga 1200 W, 80 hingga 90 Hz dan 19.2 hingga 21.6 mms^{-1} digunakan. Kemudian, eksperimen yang komprehensif dengan menggabungkan komponen campuran Cr dan Mo bersama faktor proses telah digunakan dalam proses laser pelapisan permukaan. Kedua-dua pemprosesan laser ini dibantu oleh gas argon pada kelajuan malar 10 $Lmin^{-1}$. Sampel yang telah di laser disediakan untuk kajian metalograpi dan dicirikan untuk menentukan sifat fizikal dan mekanikal. Kajian metalografi dan analisis komposisi kimia dijalankan menggunakan mikroskop pengimbas elektron yang disepadukan dengan spektroskopi sinar-x penyebaran tenaga. Sistem XRD dengan radiasi Cu Kα dan panjang gelombang 1.54 Å digunakan untuk mengesan kristal dan fasa permukaan yang telah diubah dengan laser. Profil permukaan diukur menggunakan sistem pengukur profilometri stylus. Manakala sifat kekerasan permukaan yang telah diubah diukur dengan menggunakan lekukan berlian mikro-Vickers. Lapisan permukaan besi tuang kelabu yang telah diubah suai dengan tambahan lapisan campuran Cr-Mo telah menunjukkan penghapusan grafit dan pembentukan struktur baru dendritik dengan saiz pembentukan zarah pada saiz 32 nm. Fasa karbida juga telah dikesan di permukaan yang terdiri daripada M_2C, M_3C_2 and $M_{23}C_6$. Kekerasan maksimum yang telah diubah suai pada besi tuang kelabu ialah 1039.7 $HV_{0.1}$ pada parameter laser 1200 W, 80 Hz dan campuran 32.3% Cr dan 67.7% Mo. Satu lagi penemuan yang penting dalam kajian ini ialah rintangan haus telah meningkat dengan membuat lapisan campuran Cr-Mo di permukaan besi tuang kelabu. Hubungan antara parameter laser dan tambahan campuran Cr-Mo dibangunkan untuk pemahaman lebih lanjut tentang kesan parameter laser pada campuran Cr-Mo. Penemuan ini penting bagi menghasilkan teknik pengerasan permukaan untuk tujuan rintangan haus, pengoksidaan dan rintangan haba terutamanya untuk komponen pelapik silinder dan cakera brek.

ABSTRACT

Recently, in industrial area, grey cast iron component parts (such as cylinder liner and break disc) experienced wear defect and corrosion due to the usage in high temperature, pressure and mechanical friction, which contribute to multifaceted, high-stress condition. The purpose of this research is to develop a modified surface layer on grey cast iron using laser melting and laser cladding. To strengthen the surface, Cr-Mo powder were added on the surface. The parameter on this process were analyzed using statistical analysis. The presented work is an investigation and modification of the laser surface of grey cast iron using pulse laser processing mode. Initial screening experimental designs was conducted and lead to more optimized detailed designs. A laser Nd:YAG system 300HPS model with 10.64 μm wavelength was used. Preliminary experiment of design of experiment 2-level factorial model were conducted in laser surface melting grey cast iron with spot size 1.0 mm, 1.2 mm, 1.4 mm and 1.7 mm to investigate optimized laser parameter and suitable spot size for the surface geometry, surface roughness and hardness. Based on the optimization laser parameter in laser surface melting, laser spot size of 1.0 mm with PP , PRF and S in range of 800 to 1200 W, 80 to 90 Hz and 19.2 to 21.6 mms^{-1} were used in laser surface cladding respectively. A comprehensive experiment that combines mixture components of Cr and Mo with process factor were used in laser surface cladding. The laser processing was constantly assisted by in line argon gas at 10 $Lmin^{-1}$. Laser processed samples were prepared for metallographic study and were characterized for physical and mechanical properties. The metallographic study and chemical composition analysis were conducted using scanning electron microscope integrated with energy dispersive x-ray spectroscopy. The crystallinity and phase detection of the modified surface were conducted using an XRD system with Cu Kα radiation and wavelength of 1.54 Å. The surface profile was measured using stylus profilometry measuring systems. The hardness properties of the modified surface were measured by micro-Vickers diamond indentation. A modified surface layer (Cr-Mo mixture added) had shown the elimination of graphite and a new structure of dendritic with the formation of particles in size of 32 nm had developed. A new phase of carbide was also detected on the surface which mainly contained of M_2C, M_3C_2 and $M_{23}C_6$. A maximum hardness modified grey cast iron of 1039.7 $HV_{0.1}$ is achieved at laser surface cladding parameter at 1200 W, 80 Hz and mixture of 32.3 % Cr and 67.7 % Mo. Another important finding was that wear resistance increases by adding the mixture of Cr and Mo on the grey cast iron surface. A relationship between laser surface parameter and mixture of Cr and Mo was established for further understanding of the effects of the laser parameters. These findings are significant to the establishment of surface hardening technique for wear resistance, oxidation and thermal resistance for cylinder liner and break disc.

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LIST OF SYMBOLS

E_P	Pulse energy
τ	Pulse width or pulse duration
S	Scan speed
d	Laser spot diameter
P_P	Peak power
T	Pulse period
z	Distance from focal position
I	High power density or laser irradiance
F	Energy density
P_{ave}	Power average
T_R	Residence Time or interaction time
η	Overlapped
λ	Laser wavelength
M^2	Beam quality
H_R	Heating rate
C_R	Cooling rate
$t_{cooling}$	Cooling period
μ	Coefficient of friction
N	Number of cycle
t	Times
f	Frequency
x	Total sliding distance
L	Length of stroke

LIST OF ABBREVIATIONS

ASTM	American Society for Testing and Materials
ANOVA	Analysis of variance
Ar	Austenite
COD	Crystallography open database
CoF	Coefficient of friction
DOE	Design of experiment
EDS	Energy dispersive spectrometer
GCI	Grey cast iron
HV	Hardness Vickers
HAZ	Heat affected zone
LSM	Laser Surface Melting
LSC	Laser surface cladding
Nd:YAG	Neodymium-doped yttrium aluminium garnet
PRF	Pulse repetition frequency
RZ	Remelting zone
RPM	Revolution per minutes
RSM	Response Surface Methodology
SEM	Scanning electron microscopy
TZ	Transform zone
TEM	Transverse electromagnetic mode
UV	Ultraviolet
XRD	X-ray diffraction

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